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A Systematic Approach and Mathematical Review to Textile Production Optimization: Implementing Lean Six Sigma DMAIC for Enhanced Product Consistency and Quality in the Field of Industrial Engineering Management

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Abstract

The main aim of this paper is to analyze the application of LSS tools to enhance efficiency and product quality within the region's textile sector. Specifically, the paper's objective is three-fold: to discuss how Lean and Six Sigma may be implemented separately, to discuss how these two improvement methodologies can be integrated, and to develop an integrated framework of Lean Six Sigma (LSS). The current research being conducted includes the use of journal articles and the use of the actual method. This gives an overview of previous frameworks and approaches to Lean and Six Sigma integration and establishes a new LSS Framework using DMAIC methodology. This study also comprises the quantitative and qualitative data collection from the survey and process evaluation in the Ready-Made Garment (RMG) factory. The research presented here outlines a comprehensive LSS strategy that would drastically cut down on defects and increase efficiency in the textile industry. According to the case, using LSS, the rework's Sigma level improved from 2.7 to 3.0, proving fewer defects. This paper introduces a novel LSS framework tailored for the textile industry, especially Small and Medium-sized Enterprises (SMEs). Building on previous research, it identifies specific challenges faced by the textile sector and recommends adopting digital technologies and environmental considerations, including Green LSS. The study offers valuable insights for practitioners aiming to implement continuous improvement approaches, particularly in SMEs, by integrating digital tools.

Keywords: Lean Six Sigma, DMAIC, Industry 4.0, Process optimization, Operational efficiency.

1 | Introduction

Lean Six Sigma (LSS) is an enhanced methodology used to identify and eliminate process inefficiencies and waste. It helps improve defects in processes while eradicating non-value-adding activities.

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Six Sigma follows the Define–Measure–Analyze–Improve–Control (DMAIC) approach, while Lean provides methods to establish LSS. When applied together, Lean and Six Sigma create an integrated approach to production management and quality enhancement, offering benefits such as lower costs, zero defects, high-quality products, and reduced waste disposal [1]. Additionally, LSS can be effectively utilized as a business improvement tool or operational management strategy, allowing companies to compete in the global market [2]. LSS acts as a quality check to assist in achieving the intended goals, including bottom-line improvements [3]. However, despite its advantages, studies on LSS in the textile and apparel industry are limited, making it difficult to find examples of apparel companies implementing this approach [4].

Key operational improvement strategies that address environmental challenges in manufacturing include Lean manufacturing, Six Sigma, and green production methods [5], [6]. Current literature suggests these three strategies complement each other, especially in minimizing waste and achieving environmental goals [7], [8]. Lean, modeled after the Toyota Production System (TPS), aims to eliminate waste, which is defined as non-value-adding activities for which customers are unwilling to pay [9]. Lean is a culture that reigns deep in Toyota's organizational structure that seeks to eradicate waste. Waste means all the non-value-adding activities that can be grouped into seven, that is, the forms that customers are not likely to pay for. This leads to a sociable structuring of the approach that is limited to variables that would be expected from the customer by the provider. In Motorola, Six Sigma, on the other line of the quadrant, signifies variation [10], [11].

LSS is a combination of two philosophies—Lean and Six Sigma—and represents a relatively new paradigm. As a result, research in this field has been growing, reflected in the increasing number of scholarly publications. However, despite this growth, there is a notable lack of large, practice-based, and well-structured literature reviews specifically focused on LSS. In contrast, numerous reviews exist on Lean and Six Sigma as separate approaches. Given the emergence of LSS, there is a growing awareness of the need to identify and understand the current state of developments in this field [11].

As mentioned earlier, numerous studies have examined the effectiveness of LSS in large organizations; however, research focusing on small companies is significantly less prevalent. Specifically, there is limited research on the application of LSS in Small and Medium-sized Enterprises (SMEs) [12]. Two notable examples of quantitative analysis in SMEs include Timans et al. [13] survey of an injection molding company and Okpala’s [14] study on SMEs in Nigeria. Research on LSS within the textile and apparel manufacturing industry is even more limited. In a literature search for the current study, only one additional peer-reviewed research article has been published since 2013 in this industry [15]. This case study aims to extend previous efforts and contribute to filling the gap in the literature on LSS in the textile and apparel industry [4].

LSS tools and techniques are designed to evaluate and measure an organization's performance while generating strategies to benchmark key aspects such as safety, quality, cost, cycle time, and operational efficiency [16]. According to Swarnakar et al. [17], Lean manufacturing focuses on removing waste from the manufacturing process, while Six Sigma aims to understand and minimize deviations within the process. Implementing Lean or Six Sigma alone cannot fully improve factors like quality, customer satisfaction, or net revenue, nor can it significantly reduce total manufacturing costs. However, these challenges can be addressed through the combined approach of LSS. In its simplest form, LSS seeks to maximize overall value and reduce production costs by leveraging the strengths of both methodologies. Key tools and techniques that support this approach include Value Stream Mapping (VSM), Just-In-Time (JIT), 5S, Kaizen, and Kanban, all of which contribute to enhancing operational efficiency and effectiveness [1].

The garment manufacturing process is rooted in spinning fibers, which may include cotton, polyester, and many more. This yarn is then woven or knitted to create a fabric of some kind that is used to construct garments. After that, the fabric is treated with dye, and a finishing process is performed to enhance the texture of the fabric. When all the garments have been checked for any defects in the fabric, patterns are developed, and size-to-size alterations are made. Depending on these patterns, the fabric is cut, and the pieces sewn together to make the garment. Once the sewing is done, the clothes are reviewed for quality issues and ironed, and all labels and tags are added. Last but not least, the apparels are packed and dispatched for delivery. The

purpose of this paper is to display the successful application of LSS at the quality level so that possible defects can be identified, minimize the defects, and maximize the profits of the company.

2 | Literature Review

According to Bhamu and Sangwan [18], Lean management is a concept that has surfaced in Japan. Manufacturing firms are in a position where they cannot afford to make giant leaps in reconstructing industries. Originally, Toyota was the first automobile company to adopt lean manufacturing and produce many different models of cars at the least cost while possessing the least amount of stock. Lean manufacturing seeks to minimize cost since all activities that are not necessary are stripped out inside a process and with more efficiency [18]. Lean thinking focuses its attention on overproduction, and Muda highlights that there are many things wrong that need to be made right.

In contrast, Six Sigma focuses its efforts on decreasing the amount of variation that occurs within a process, according to Lertwattanapongchai and Swierczek [19]. The Ready-Made Garment (RMG) sector is important in many developing countries, including Bangladesh, India, Vietnam, and China. They described this as a labor-intensive industry forced to adopt higher efficiency rates, cut costs, and provide quality products as they competed internationally. LSS, which enriches the whole spectrum of waste minimization principles and process enhancement from Lean and Six Sigma approaches, constitutes an appropriate response to these challenges.

The Define, Measure, Analyze, Improve, Control (DMAIC) concept is the philosophy on which Six Sigma is based and can often be implemented as a framework to solve process issues. In the RMG sector, defects and inefficiencies are prevalent, and hence, the DMAIC, through LSS, offers great prospects for improvement. In this literature review, an effort has been made to move through the lenses and see how LSS and the DMAIC approach work for the RMG sector, especially in terms of quality enhancement, process enhancement, and reduction in waste.

Shah and Ward [20] also continued to consider that pointing at Lean as a toolkit is misleading; Lean is a system of systems, and it is a socio-technical system. Hadid et al. [21] expanded on this purview by examining the moderating effect of Lean social practices on technical practices against the index of financial and operations performance. This support for the social and technical aspects of Lean takes back to the ideology that was practiced by Toyota, which aimed at productivity efficiency through practices such as the elimination of waste but also recognized the humanity aspect, as stated by Ohno [22]. Lean has adopted some principles in the RMG sector in its effort to eliminate waste in the business processes.

Out of the four central subsets included in Deming's system of profound knowledge, perhaps the best known is that which deals with variation, which was explained by the red bead experiment [23]. Deming, on the other hand, postulates that there are two sorts of causes of variation, known as common causes and specific causes. Randomness (or common cause) is by its very nature always present, whereas special causes are born out of unplanned or unwanted focus [24]. Thus, variation within the process is always inherited and is almost impossible to eradicate. According to Bergman and Kroslid [25], understanding variation is one of the key requirements when using the Six Sigma approach. Therefore, Six Sigma's philosophies, when it comes to improving processes, focus on this concept of variation. The standard Six Sigma mainly deals with the aspect of reducing defects. It has been implemented successfully in RMG to control the defect rates, which are very sensitive to export products. With the help of Six Sigma, much effort has been made to ensure that the garments produced are of high quality and are of international standards.

Sharma [26] depicted the advantage of blending Lean and Six Sigma strategies in that organizational objectives are set strategically by the top management, followed by a practice of QFD to prioritize the working project. The QFD approach can also be identified as a more complex process than the selection of CI tools [27]. The implementation of Lean and Six Sigma has been introduced in the RMG sector, both being the methods that focus on different yet combinable sides of organizational function. Some research has also described that the

integration between waste minimization (Lean) and better quality (Six Sigma) has resulted in better cost reduction and quality enhancement. The RMG sector often came across a complex issue of where to begin improvement. To shift this paradigm, LSS under the DMAIC structure offered a solution for companies to improve. Process improvement was done, eliminating waste or any variation in the procedure undergoing and stealing consistency for efficiency.

LSS concepts have been apparently proven to yield tangible results in terms of lead time decrease as well as RMG production line productivity. Moreover, another study by [28] suggested the way DMAIC uplifted the sewing operation by focusing on eliminating bottlenecks so that productivity increased by 15%. The Define phase assisted in defining certain issues, including machine downtime, while the Measure stage ensured that key performance indicators were put into measurements. Likewise, in the Analyze phase, sources of these problems were established, and in the Improve phase, needed adjustments were made, culminating in Improvement.

Despite the overall effectiveness, there is also a body of literature on Lean application experiences, and failure rates are 50 %-60 % or even 80 %-90 % [29]. Regrettably, it has been ascertained that there can be no definitive Lean recipe that can be followed to the letter. However, there are a few limitations that LSS encounters when being implemented in the RMG sector, such as cultural interoperability, scarcity of skilled workforce, and insufficient training. Although Lean Six Sigma (LSS) can significantly improve productivity, its implementation is often hindered by employees' resistance to change and organizations' reluctance to invest in continuous education. Additionally, the dynamic nature of the garment industry and the challenges faced by small and medium enterprises make the effective application of the DMAIC methodology quite complex.

Additionally, the extent of sustainability of enhancements attained based on LSS within the RMG segment forms another significant analysis agenda. Some studies presume that a proactive approach might be used to improve organizational performance with the help of the LSS initiatives in the short term. However, these improvements should be permanently monitored and controlled. For example, maintaining the other improvements in quality and effectiveness through DMAIC's Control phase, which was done by Khan et al. [30], was crucial. However, such improvements tend to call for backing from top organizational management and recurrent training of its employees.

The literature presents an opportunity where LSS and DMAIC have attempted to reveal their applicability in the RMG sector; however, several research gaps are highlighted. Large, structured garment factories are the main research subjects, but SMEs have not attracted much attention so far. Besides, there is scarce information on the virtue of sustaining LSS projects, especially when it comes to maintaining constant cycle improvements. Moreover, the literature related to the environmental impacts of LSS in connection with lowered waste and energy usage is modest. It poses a research gap that was identified in this paper.

The present study, therefore, intends to extend this knowledge by examining the actual implementation of LSS in the context of small and medium RMG enterprises, which, in many ways, may differ considerably from large factory complexes. Furthermore, the impact of DMAIC when integrated with Industry 4.0 technologies, including automation and digital tracking in LSS, will be discussed in this study as well. This research will help in the gap to know how IT supports LSS for the RMG sector.

To sum up, it can be stated that LSS and its DMAIC approach promise great improvement at the level of operations, products, costs, and, more importantly, waste in the organization of the RMG sector. Nevertheless, the literature presents the difficulties inherent to its application, especially among SMEs, regarding the necessity of constant durability. By filling these gaps, subsequent research can provide useful information on how to adapt LSS to the continuously changing requirements of the RMG sector, particularly in the context of digitalization.

3 | Methodology

Thus, it is quite clear that the Bangladeshi RMG industry sector has made a tremendous leap forward in recent years. Nevertheless, there are still persistent issues regarding efficiency, productivity, workplace safety, and finally, value appropriation. Previous research literature has been concerned only with the positive outcomes of lean practices but does not report the current state of lean practice in the Bangladeshi RMG sector [31]. Lean manufacturing refers to the manufacturing approach that is basically aimed at the reduction of waste in the production line. The application of lean principles results in improvement processes in the RMG sector, where global demand is highly focused on fast, high-quality, and low-cost production. The key point in relation to this is that RMG companies must first identify where waste exists and then work to reduce its level, as waste reductions translate into improved productivity and efficiency, reduced expenses, and improved profitability.

Lean manufacturing highlights eight types of waste that are especially relevant to the RMG industry. These wastes, often grouped under the acronym TIMWOOD+S, can significantly hinder efficiency and profitability in garment production.

Transport is the unnecessary movement of materials between workstations or factories. This can lead to delays and increased costs. Inventory refers to excess stock, such as unused fabrics or finished garments, which ties up capital and takes up valuable space. Motion involves unnecessary worker movement, which can reduce productivity and lead to fatigue. Waiting occurs when there are delays due to machine repairs, material shortages, or slow approvals, disrupting the production flow.

This is where manufacturers produce more clothes than required, mainly leading to many unsold clothes, causing high storage expenses. The main theme of overprocessing is the inclusion of operations that do not add value to the perception of the purchaser of the final product. A defect is a weakness in the manufacturing process, for example, poor workmanship in sewing or size, which may cause the material to be rejected and must be produced again. Skills are defined as employees' potential that is not fully utilized through proper assignment or development.

Lean tools are essential for reducing waste and improving efficiency in the RMG industry. VSM is a visual tool that helps identify areas of waste in the production process. By mapping the entire flow, factories can pinpoint bottlenecks, unnecessary transportation, and inefficient workstations. 5S is a workplace organization method that promotes a clean, organized, and efficient work environment. By reducing the time spent searching for tools or materials, 5S can improve productivity on production lines. Just-in-Time (JIT) is a principle that aims to minimize inventory waste by producing garments only when needed. This reduces the costs associated with storing excess materials. Kaizen is a continuous improvement approach that encourages workers to suggest small, incremental changes to improve processes.

This can enhance both productivity and job satisfaction. Kanban is a visual system for managing inventory and workflow. By ensuring materials arrive just as they are needed, Kanban can help reduce overproduction and excess inventory. In this paper, our main aim is to identify the wastage by lean manufacturing processes and minimize this wastage, hence improving the quality of Six Sigma. So, the research surveying method will be conducted using both quantitative and qualitative questionnaires and the integration of both lean and Six Sigma in RMG sectors. This paper mainly focused on the DMAIC principle to identify wastage and, hence, minimize it with excellent quality [32].

3.1 | Define Phase

In this phase, the paper discussed the identification of problems of wastage and quality in the RMG sectors. In the initial stage, due to the poor quality of garments, there were surveys of four different buyers, which were the internal and external teams of buyers. So, first, we will highlight the current floor sewing layout and the problems that are occurring. The problems raised were due to the huge amounts of work in process and the lack of proper layout, which means the traditional batch-wise layout of each section of the sewing floor.

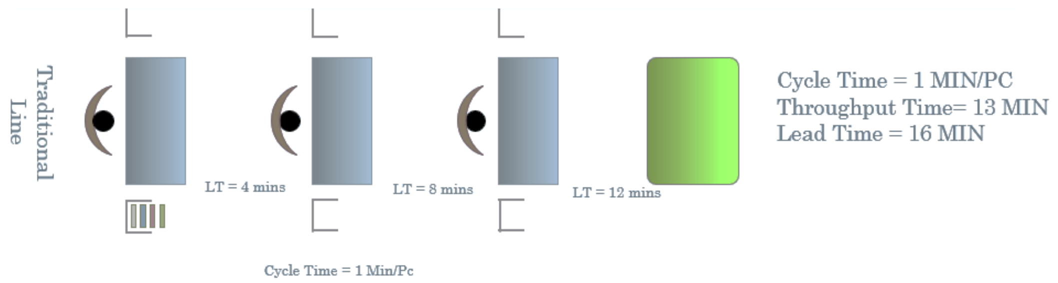

Fig. 1. Traditional view of batch-wise layout.

The ratings were considered to be from 1 to 10 for different criteria, and the four buyers were C&A, LIDL, Pentax, and H&M.

Table 1. Survey for importance and customer satisfaction value.

No.	Criteria	Importance				Satisfaction			
		Buyer				Buyer			
		C&A	LIDL	Pentax	H&M	C&A	LIDL	Pentax	H&M
1	Knowledge of employees about jobs	5	6	4	5	6	5	4	5
2	Simplicity of the operation	4	3	5	6	5	4	5	6
3	Idea about bottleneck operation	5	4	5	6	7	5	5	6
4	Wait time for Work	6	8	4	5	5	7	4	5
5	Idle time for resources	4	7	6	5	7	6	6	5
6	Provision of incorrect information	5	6	5	6	6	6	5	6
7	Tendency of mass inspection	5	5	5	6	4	6	5	6
8	Consciousness about inventory	5	5	5	6	6	7	5	6
9	Designed ergonomics	7	5	5	4	6	4	5	4
10	Extra processing steps	8	4	4	4	7	5	4	4
11	Prolonging production cycle time	5	5	5	3	4	5	5	3
12	Knowledge of Critical Process	6	6	5	4	5	8	5	4

Customers took 10 polo shirts as samples and measured the shoulder length of each garment, getting different results for each garment.

Table 2. USL and LSL calculations of Polo-shirt.

Sample No.	Item	Measurement of Shoulder width	Mean	St. Dev.	USL (Mean + 3σ)	LSL (Mean - 3σ)
1	Polo-Shirt	10.5	10.77	0.19	11.34	10.20
2	Polo-Shirt	10.8	10.77	0.19	11.34	10.20
3	Polo-Shirt	11.1	10.77	0.19	11.34	10.20
4	Polo-Shirt	10.6	10.77	0.19	11.34	10.20
5	Polo-Shirt	10.9	10.77	0.19	11.34	10.20
6	Polo-Shirt	10.7	10.77	0.19	11.34	10.20
7	Polo-Shirt	10.8	10.77	0.19	11.34	10.20
8	Polo-Shirt	10.6	10.77	0.19	11.34	10.20
9	Polo-Shirt	11	10.77	0.19	11.34	10.20
10	Polo-Shirt	10.7	10.77	0.19	11.34	10.20

3.2 | Measure Phase

In the measure phase, the paper measured the current Cp level and Defect per Million Opportunities (DPMO) of the manufacturing industry's products. Process capability is a statistical analysis tool. Measurement of process capability basically means quantification of the capability of a stable process to produce parts within the specification limits. These are: Cp=Process Potential Index; Cpk=Process Performance Index USL=Upper specifications limits L= Lower specifications limits.

Allowable Process Spread = (USL-LSL)/ Actual Process Spread (6 σ).

If a manufacturer wants to be ensured that he is producing products of good quality, he must ensure that the actual process spread does not exceed the allowable process spread. By minimizing waste & ensuring good quality, one can expect good motives from the potential customers. The value of Cp must be greater than 1, but when its value is less than 1, it may be stable but not capable of producing parts within a specification limit.

As per *Table 2*, the Cp value is 1<2, which means the process meets specifications but has no margin for variation.

The importance value and satisfaction value have been described considering the criteria and also calculated importance index and satisfaction index of each criterion so that it reflect the overall performance of the selected criteria.

Table 3. The performance index value for customer satisfaction criteria.

No.	Criteria	Importance Value (μi)	Satisfaction Value (μs)	Importance Index (Pi)	Satisfaction Index (Ps)
1	Knowledge of employees about jobs	5.00	5.00	0.83	0.83
2	Simplicity of the operation	4.50	5.00	0.75	0.83
3	Idea about bottleneck operation	5.00	5.75	0.83	0.82
4	Wait time for Work	5.75	5.25	0.72	0.75
5	Idle time for resources	5.50	6.00	0.79	0.86
6	Provision of incorrect information	5.50	5.75	0.92	0.96
7	Tendency of mass inspection	5.25	5.25	0.88	0.88
8	Consciousness about inventory	5.25	6.00	0.88	0.86
9	Designed ergonomics	5.25	4.75	0.75	0.79
10	Extra processing steps	5.00	5.00	0.63	0.71
11	Prolonging production cycle time	4.50	4.25	0.90	0.85
12	Knowledge of Critical Process	5.25	5.50	0.88	0.69

At this phase, the percentage of defects, existing DPMO, and calculation of the Sigma Level of Esquire Knit Composite Ltd indicated are described below.

Table 4. DPMO and sigma level of the existing process.

Total Checked Pcs	3500
Number of Defects	470
(%) of Defectives (DPO)	13.43%
DMPO	134286
Sigma Level	2.40

The frequency of defects in Polo shirts is a detailed view.

Table 5. Frequency of defects of the inspected polo shirts.

Defects	Real Occurrence	(%) Of Occurrence
Skip stich	45	9.57
Down Stich	37	7.87
Broken Stich	134	28.51
Raw Edge	42	8.94
Joint Stitch	35	7.45
Uneven Stich	38	8.09
Spot/Oil Spot	25	5.32
Hole/Damage	15	3.19
Puckering	39	8.30
Reject	7	1.49
Slanted	5	1.06
Uncut Thread	2	0.43
Reverse	19	4.04
Size mistake	4	0.85
Process Missing	23	4.89
Total	470	100.00

3.3 | Analyze Phase

To solve the defects, the paper analyzed two tools: brainstorming and a cause and cause-effect diagram.

Brainstorming: Brainstorming is an essential problem-solving tool. The goal of this tool is to identify the issues, solutions, and opportunities. To find out the potential causes of the defects and their respective solutions, we arranged a brainstorming session where they applied the round-robin method with the presence of the following members, which are shown in *Table 6*.

Table 6. Attendants at the brainstorming session.

Attendance	Number
Floor production manager	1
Floor Industrial Engineer (IE)	2
End-line table quality	2
Quality manager	1
Multi-skilled operator	2
Floor technician	1
Floor sewing in charge	1

The cause-effect diagrams showed the possible reasons for the problems of broken stitches that occurred more during the inspections. This diagram will help to solve the most frequent problems.

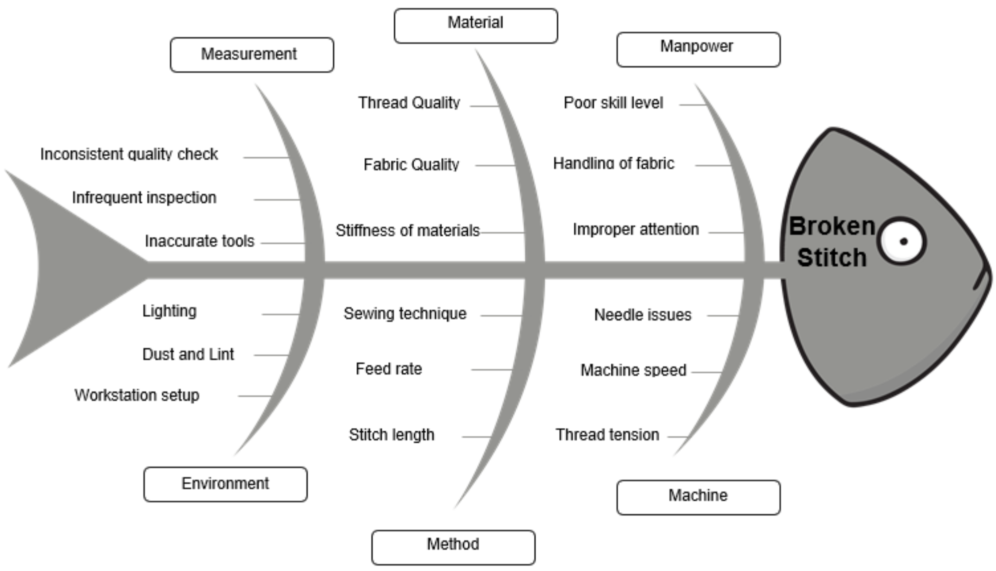

Fig. 2. Cause and effect diagrams for broken stitch.

3.4 | Improve Phase

The target is to implement actions to correct the problems identified in the previous stage. These actions need to be tested and measured to verify that they are effective. This improvement phase involves brainstorming potential solutions, selecting solutions to test, and evaluating the results of the implemented solutions. Often, pilot implementation is conducted before a full-scale rollout of improvements.

This study tried to suggest some potential solutions to minimize the causes of defects through Brainstorming, direct observation, and literature review. *Table 7* gives the necessary solutions with their corresponding causes.

Table 7. Suggested solutions against causes of defects.

Areas	Causes	Suggested Solution
Man	Inadequate training and operator inefficiency	Trained and motivated operators sufficiently
	Negligence	Improved supervision
Machine	The machine is threaded incorrectly or excessive thread tension	Rethread the machine and maintain proper thread tensions.
	Excessive pressure on the pressure on the pressure on the pressure on the pressure on the presser foot.	Minimizing the pressure on the pressure on the pressure on the pressure on the pressure on the pressure on the pressure on the pressure on the pressure on the pressure on the pressure on the pressure on the pressure on the presser foot.
Method	Took Much Time to Complete the sewing	To train the operator the standard way from the ref video.
	Alteration occurs as puckering	The technician will give her a mockup to copy.
Material	Poor selection of Needle number	Needle policy should strictly maintain.
	The quality of the Thread not good	Discuss with the merchandiser to improve the thread.
	Finished Pattern Not checked after 6 days	The finished pattern should be checked weekly by a technician.

Table 7. Continued.

Areas	Causes	Suggested Solution
Management	Top management was sometimes unwilling to follow the operation	Should be sat on the Mid-Mad management Weekly basis.
	Short term thinking	Should thin for the long-term goal.
	No documentation of ARY work	Documentation needs of progress.
Environment	Rough environment for the workers	Using slag should be prohibited and minimum S.S.C passed workforces should hire.
	Compliance issue	Compliance should be practiced more and more.
	Work environment	Work Environment should be friendly for process operations (light, noise, cleanness).

Based on the solutions provided by this study, we took some corrective actions mentioned in *Table 8*. We implemented it into two pilot sewing lines in the manufacturing industry, and the total number of machines was 80.

Table 8. Corrective actions taken.

Corrective Action	Criteria
Giving mockup	To each process
5S implementation of both line	Strictly
Standard Method of process-wise operation showed by technician	Process to process
Morning Meeting with top three defeats	At 8.00 AM Regularly
Needle uses 11 number and changes regularly	Within 2 days
Training provided machines and operators	2 hours each day

3.5 | Control Phase

After the implementation of the solutions, we shared the progressive outcomes with the management. The main defects were recognized and partially reduced in number. Now, the challenge is to withstand progress and to refine the system continuously. For this purpose, a control plan is prepared.

Control plan

The management needs to take the initiative on the following obligatory activities to withstand progress after Six Sigma implementation:

Step 1. Arranged morning meetings with line-wise operators, helpers, and staff to point out quality issues.
Step 2. A mockup should be given, and the signature of the responsible process-wise operators needs to be taken.

Step 3. Motivation, Reward, and incentive systems should be introduced to the zero defective lines.

Step 4. QMS team should be involved and make a risk analysis chart.

Step 5. The top three defects should be highlighted in the dashboard daily.

4 | Result and Discussion

We implemented all the suggested solutions into one of their pilots' sewing lines. After the implementation of the solutions' percentage of defectives, we calculated DPMO and Sigma Level by using the previous sigma level formula, which is reported in *Table 9*.

Table 9. DPMO and sigma level after improvement.

Total Checked Pcs	6000
Number of Defects	435
(%) Defects	7.25
DPO	0.0725
DMPO	72500
Sigma Level	3.0

By identifying the non-value-added work, the company took corrective action to eliminate this, such as excess motions, excess operator, thread cutting operator, process quality, rework, altered percentage, and overtime hours. Using the VSM tool from LSS helps to identify the sources of waste, such as waiting, overprocessing, defects, or excess motion. By minimizing the waste, the flow of materials and information gets smoother, and the amount of WIP in each stage is reduced. Using the lean tool Single Minute Exchange of Dye (SMED) helps to take less time from previous layout time and, with effective ways, can save time. Ultimately, we save money. Traditional garment industries are facing problems like low productivity, longer production lead time, high rework and rejection, poor line balancing, low flexibility of changeover, etc.

These problems are addressed and sorted out by implementing lean tools like Jit, SMED, and Single piece flow. By using DMAIC, we found the sigma level to be 2.70 to 3.00, which is improved. For any industry, sigma level 4.0 is standard. The following Six Sigma helps significantly to minimize the defects, rework the percentage of a factory, and minimize waste. Using the LSS method helps to cut excess costs by identifying waste and the defect percentage to satisfy customer demand, which is good for the sustainable development of any garment industry.

5 | Conclusion

The conclusion section of the thesis paper gives a detailed argument of LSS for the Textile Industry' specifically in terms of improving quality and eliminating waste. The findings concerning the case reported in the paper demonstrate how the DMAIC model helped to enhance manufacturing and minimize defects after defining, measuring, analyzing, and improving the process. For example, after LSS implementation, the Sigma level of the processes increased from 2.7 to 3.0, seized a wide number of defects, and imparted general effectiveness.

The research paper stresses that although Lean and Six Sigma initiatives may have been criticized as 'only' tools to reduce waste, they can yield major improvements in efficiency, cost, and quality. What ousted processes like VSM and Single Minute Exchange of Dies (SMED) to reduce its manufacturing cycle time and improve the flow of work. The non-value-added activities at GE were eradicated as Tom carried out LSS, which helped him achieve a better flow of materials and manage to lessen work-in-process inventory.

However, the paper outlined some constraints and difficulties that might hamper the effective implementation of LSS, so the textile industry is highlighted below. One major difficulty is the fact that a major outlay is necessary initially to train employees and upgrade technology; this situation is especially difficult for SMEs. Also, there is always the problem of creating resistance to change, as the workers may be used to operating in the conformist method and would not opt for change willingly. Due to differences in textile processes that include spinning, weaving, dyeing, finishing, etc., it has been quite challenging to apply LSS on a common platform across the textile industry.

Another important limitation mentioned in the paper is the absence of an integrated digital system for acquiring data and analyzing it in real-time; this makes it impossible to observe the processes constantly and locate the sources of variability frequently. This is especially because the textile industry is more prevalent in many developing countries, and these firms depend on cheap labor as well as manual methods when handling

different processes, thus making it difficult to adopt automated and innovative ways of handling data and information.

In the following, the paper offers several suggestions for the removal of such barriers to aid the continual improvement of LSS's efficiency in the textile industry. Industry 4.0 involves using automation, the matter of things, and learning machines in the manufacturing system, which, as such, can increase the efficiency of data gathering and processing, hence improving the existing process control. Furthermore, implementing what is referred to as 'Green LSS' could assist companies in attaining sustainability objectives thanks to the efforts that will reduce energy use during processes such as dyeing.

It has also been found in this study that, though the textile industry is different from other industries in nature, there is considerable potential to implement LSS. Having merged digital technologies and dedication to improvement, LSS has an opportunity to turn the textile industry into a leaner and more agile sector that is ready to face new challenges and conform to new norms in terms of demand and sustainability. Further, it might also be beneficial for organizations to experiment with different simulation models of LSS interventions in anticipation of a full implementation so that the effects of different interventions may be measured in terms of bottlenecks and process efficiency prior to the implementation of any radical changes.

In conclusion, the thesis contributes to the claim that LSS can enhance the efficiency and eventual sustainability of textile enterprises if firms are open to enhancing the physical and human capital required for the methodology. The prospects for the LSS in this sector are quite favorable, if not for the integration of modern IT tools that allow real-time monitoring and performance analytics.

5.1 | Limitations and Scope of the Future Work

The application of LSS in the textile industry is highly promising and provides great prospects for the future. It has its constraints and can further develop potentialities. One of the challenges is the need for large initial investment, both for the training of new employees and for the acquisition of the necessary technologies and equipment, which presents a challenge for Small and Medium Enterprises in the textile sector. Moreover, there is resistance to change because employees of textile manufacturing often are used to performing their work in accordance with the old techniques. The structure of the industry, in terms of the different product and process varieties that characterize the spinning, weaving, dyeing, as well as the finishing stages, hampers uniform LSS deployment.

The fourth of those limitations is the use of real-time data for performance monitoring and for the identification of causal relationships, an element that is very difficult in many textile environments since the infrastructure needed for the proper collection and analysis of data is often absent. However, the textile supply chain needs many players, and the synchronization of processes is not easy due to too many players involved. Evidently, many traditional techniques have not been computerized and demand much labor input in the TM sector well, especially in developing countries where labor is very cheap, leading to hardly manageable variability. The last and most important factor is the Richness of raw material and quality differences, as well as the high degree of product differentiation, which restricts LSS application.

Despite this, it is evident that there is a considerable opportunity for future work in LSS within the textile sector. Using IoT as part of the integration of digitalization and other forms of data analysis can also enhance the availability of data and continuous process monitoring. Some problems that are described by authors now are related to manual variability, and the introduction of Automation and AI could be the solution to decrease it and improve the quality of the products. Since textile processes possess their kind of characteristics, it would be relatively easy to solve the problems by developing special tools and frameworks for LSS. One of the common ideas that people come up with is the differentiation of LSS practices from one state to another of production. However, making those differences well-defined might reduce the ease of training for improvement across the company.

Moreover, it is likely that LSS can also improve supply chain integration as people can learn to develop related quality standards together. Apart from that, using 'Green LSS' could also enable the organization to sustain process improvement initiatives together with environmental conservation objectives – as it pertains to water and energy utilization within the dyeing process. Also, new courses that are tailored towards change management can meet the human resource, with the aim of nurturing a changing culture in the organization. It also allows companies in the textile industry to experiment with the LSS interventions in simulation models before implementation. Finally, the adoption of Industry 4.0 solutions, such as utilizing blockchain for transparency and machine learning for prognosis, can supplement LSS by making processes more optimized, robust, and transparent. These future directions also highlight the fact that LSS can revolutionize the textile industry in the future by making it leaner, meaner, and more able to adapt to future changes.

Author Contributions

Chandan Chandra Sheel was responsible for the conceptualization, methodology, and design of the study. The author conducted the mathematical modeling and analysis related to textile production optimization using the Lean Six Sigma DMAIC framework. Chandan Chandra Sheel also contributed to the data collection, interpretation of results, and the writing and revision of the manuscript.

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Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The author declares no conflicts of interest related to this research.

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